Resource Abundance, Market Size, and the Choice of Technology

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Abstract

How resource abundance and market size affect the choice of increasing returns technologies is studied in an overlapping-generations general equilibrium model in which manufacturing firms engage in oligopolistic competition. The model is surprisingly tractable. First, for the steady state, the wage rate, the level of technology, and capital stock are not affected by the amount of natural resources. An increase in the share of agricultural revenue going to natural resources leads to a lower wage rate and firms choose less advanced technologies. Second, an increase in market size increases the equilibrium wage rate, level of technology, and capital stock. Finally, other things equal, a country with a lower endowment of natural resources or a higher market size has a comparative advantage in producing the manufactured good.

Keywords: Technology choice, resource abundance, specific-factors model, overlapping-generations model, increasing returns

JEL Classification Numbers: F10, N60, O14

1. Introduction

One interesting observation on Britain and the United States is that the wage rate in the U.S. was higher than that in Britain (Young, 1928; Rothbarth, 1946). How to explain this difference? Young (1928) argues that the size of the American market was larger than that of Britain. Thus, American firms chose mass production technologies and workers enjoyed a higher wage rate. Rothbarth (1946) thinks that the size of the American market in the 19th century may not have been larger than that of Britain.[2] One explanation he proposes is that American endowment of natural resources was larger than that of Britain. With abundant supply of land, American firms adopted technologies economizing the usage of labor.[3] Habakkuk (1962) provides a comprehensive discussion of American and British technologies in the 19th century, and his approaches for addressing technology adoption and wage difference between the two countries were explored by other scholars in their more quantitative studies.

[1] I thank Gulcin Ozkan, David Selover, Lei Wen, and two anonymous reviewers for their valuable suggestions. I am solely responsible for all remaining errors.

[2] Temin (1966) also thinks that the size of the American market was not larger than that of Britain in the 19th century.

[3] To explain why Britain was the first country to achieve industrial revolution, Allen (2009) has argued that resource abundance such as the amount of coal available played a significant role affecting technology choices in Britain. Allen (2014) discusses how factor prices affect technology choices in a global perspective.

As evident from Britain and the United States, difference in technology adoption among countries is a general issue. In their systematic empirical research on historical technology adoption, Comin and Hobijn (2004) have found significant technology adoption lags among developed countries. Difference in technology adoption among countries has important implications. In their study on the diffusion of 15 technologies for 166 countries, Comin and Hobijn (2010) find that cross-country variation in technology adoptions accounts for more than one quarter of per capita income differences among countries.

In the literature, with a Cobb-Douglass production function in the manufacturing sector featuring constant returns, it is difficult to model a firm's technology choice: if countries have access to the same set of technologies, a firm's choice of technology and choice of inputs cannot be differentiated. Specifically, if K is the amount of capital and L is the amount of labor, output is $K^{\zeta}L^{1-\zeta}$, where ζ is a constant between zero and one. Since countries are assumed to have the same production function $K^{\zeta}L^{1-\zeta}$, technology choice in the literature means that countries choose different values of K and L in producing the manufactured good. We may have hoped that different choices of ζ among countries could be used to capture different choices of technologies. However, countries are assumed to have the same ζ in the literature to ensure that results are comparable among countries.

In this paper, we study how a firm's technology choice is affected by resource abundance and market size in an overlapping-generations model. In this general equilibrium model, manufacturing firms engage in oligopolistic competition and choose technologies to maximize profits.[4] There is a continuum of technologies with distinct levels of fixed and marginal costs. The existence of fixed costs leads to increasing returns in the manufacturing sector.[5] A manufacturing firm's choice of technology and its choice of inputs through the choice of output are two distinct things even though they are related. While countries *ex ante* differ in resource abundances only, they choose different technologies in equilibrium *ex post*. The assumption that *ex ante* countries have access to the same set of technologies and differ only in resource endowments ensures that results are comparable among countries, while the result that countries choose different

[4] Oligopoly is an important type of market structure (Chandler, 1990). Since the end of the 19th century and the start of the 20th century, many important industries in the United States such as the steel industry became oligopolistic.

[5] The existence of increasing returns is frequently discussed in Habakkuk (1962). Increasing returns can be captured by the existence of fixed costs of production. With fixed costs, market structure will be imperfect competition. Oligopoly used in this model is a convenient type of market structure to study the choice of increasing returns technologies.

technologies in equilibrium is very valuable in explaining empirical evidence. Scholars such as Clarke and Summers (1980) and James and Skinner (1985) have suggested that allowing technological differences among countries is essential in explaining empirical evidence.

In this model, labor and land are used to produce the agricultural good, and labor and capital are used to produce the manufactured good. While the amount of capital is endogenously determined, the amount of land is exogenously given and is used to measure resource abundance. It is interesting that the model is tractable. First, for the steady state, we show that an increase in the share of agricultural revenue going to labor increases the wage rate and induces firms to choose more advanced technologies. An increase in the percentage of income spent on the manufactured good increases the wage rate and firms adopt more advanced technologies. Those results are consistent with the observations that the relative value of land decreases and an increased percentage of income is spent on manufactured goods during the process of economic development.

Second, an increase in the degree of patience of an individual increases a country's comparative advantage in producing the manufactured good. This is consistent with the argument that high saving rates contributed to economic takeoffs in East Asia. With capital accumulated through high saving rate, economies such as South Korea have established comparative advantage in exporting capital-intensive goods.

Third, we study the impact of resource abundance on technology choice. We show that the wage rate and the equilibrium level of technology are not affected by the amount of land. However, an increase in the share of agricultural revenue going to land decreases the wage rate and the equilibrium level of technology. We also show that a change in the amount of natural resources does not affect the equilibrium interest rate. This result is useful for the debate in economic history. It has been argued that a higher amount of resources leads to a lower interest rate. Here we show there is no monotonic relationship between the interest rate and resource endowment.

Finally, we study the impact of market size on technology choice. The size of the market can be measured by the product of the wage rate and the size of the population. Since the wage rate is endogenously determined in this model, the size of the market is ultimately measured by the size of the population. We show that an increase in the size of the population increases the wage rate and the equilibrium level of technology. The importance of market size in technology choice is supported by empirical evidence. For example, in their study on the market for passenger vehicles, Klier, Linn, and Zhou (2016) have found a strong connection between market size and technology adoption.

In the literature, Rothbarth (1946) provides intuitive arguments on how resource abundance affects technology choice. In Temin (1966, 1971), labor, capital, and land are the three factors of production.[6] For a country with abundant resources, a higher wage rate in the manufacturing sector is associated with a lower labor-capital ratio, thus a lower interest rate. Temin (1966) raises the question that while the American wage rate might be higher than that in Britain, the American interest rate was significantly higher than that in Britain. To explain the puzzle raised by Temin, Clarke and Summers (1980) have shown that demand elasticity of agricultural goods is a crucial factor in affecting the impact of land endowment on the wage rate in their dynamic model. They also provide empirical evidence that the real interest rate in the US might not be significantly higher than that in Britain. James and Skinner (1985) have studied a computable general equilibrium model in which labor may be skilled or unskilled. They argue that while some manufacturing sectors had higher capital-labor ratios in America than those in Britain, in general capital-labor ratio in America might not be higher than that in Britain. One major difference between the above papers and this one is that this paper focuses on the choice of increasing returns technologies while the above papers focus on constant returns technologies.

With land specific to the agricultural sector and capital specific to the manufacturing sector, this paper is related to the literature on specific-factors models in international trade, especially Eaton (1987). Eaton has studied a dynamic model in which land is both a factor of production and an asset. Like his model, clearance of the asset market plays a significant role in this paper. There are some significant differences between his model and this one. In his model, firms in the manufacturing sector engage in perfect competition and technology choice is not addressed. In this model, firms in the manufacturing sector engage in oligopolistic competition and technology choice is an essential component of this model.

For models on the choice of technology, Zhou (2004) establishes mutual dependence between the size of the market and the division of labor in a general equilibrium model. Zhou (2007) studies impacts of factor endowment on the volume of international trade. In Zhou (2007),

[6] Temin (1971, p. 253) argues that Rothbarth (1946)'s statement "labor-saving equipment" does not differentiate two cases: whether it saves labor by providing more machinery per worker or better machinery. The usage of better machines is related to the study of the direction of technical change (Acemoglu, 2010).

though countries only differ in factor endowment *ex ante*, they may also differ in their chosen technologies. If industries choose the same capital-labor intensity in equilibrium, the volume of international trade is zero. This explains why actual volume of trade is lower than that predicted by traditional models. There are some significant differences between this model and Zhou (2004, 2007). First, land is not a factor of production in Zhou (2004, 2007). Thus, the impact of resource abundance (captured by the amount of land in this model) on technology choice is not addressed in Zhou (2004, 2007). Second, Zhou (2004) and Zhou (2007) are one-period models while this one is an overlapping-generations model. An overlapping-generations model is useful to address the endogenous accumulation of capital and makes the existence of an asset market possible. Asset market equilibrium plays a key role in deriving results such as Proposition 2 in this paper. Yu (2011) has studied how the choice of technology is affected by coordination costs. Zhou and Zhou (2016) have studied an overlapping-generations model in which there is unemployment in the manufacturing sector. However, impact of resource abundance on technology choice is not addressed in their model.

The plan of the paper is as follows. Section 2 specifies the model. Section 3 conducts comparative statics to explore the properties of the steady state. Section 4 discusses some potential generalizations and extensions of the model and concludes. The Appendix contains discussion of stability of the steady state.

2. The model

In this paper, subscripts of variables will be used to denote time period, and superscripts will be used to denote the sector of production. To establish a country's comparative advantage, we focus on a closed economy. The motivation of this assumption is as follows. In the 19th century, the United States implemented high tariffs to encourage the production of manufactured goods (Chang, 2003). Transportation costs in the early 19th century were also relatively high. Overall, the impact of international trade on the American economy at that time might not be very significant. Before the significant expansion of international trade after World War II, domestic supplies of resources and market size were crucial factors in determining firms' technology choices in a country (Nelson and Wright, 1992).

In this overlapping-generations model with perfect foresight (Zhang, 2002), each person lives for two periods: young and old. In each period, L young persons are born and L old ones die.

Thus, the size of the population does not change over time. A person derives utility from the consumption of the agricultural good and the manufactured good. The agricultural good is used for consumption only. The manufactured good may be used for either consumption or capital accumulation. For simplicity, we assume that one unit of the manufactured good can produce one unit of capital (Eaton, 1987, p. 327; Drazen and Eckstein, 1988, p. 432). Thus, the price of capital equals the price of the manufactured good.

Labor, capital, and land are the three factors of production. First, a person supplies one unit of labor only when he is young. The wage rate is w_t. Second, the amount of capital in period t is K_t, which is endogenously determined by the amount of saving of individuals. The interest rate is r_t. Like Eaton (1987), we assume that capital does not depreciate. Third, the amount of land is T and it does not change over time. The level of rent to land in period t is μ_t.

2.1. Individual behavior

An individual's discount factor is ρ. For an individual born in period t, for the constant $\theta \in (0, 1)$, his utility function is specified as

$$U(c_{t,1}^a, c_{t,1}^m, c_{t+1,2}^a, c_{t+1,2}^m) = \theta ln c_{t,1}^a + (1-\theta) ln c_{t,1}^m + \rho\theta ln c_{t+1,2}^a + \rho(1-\theta) ln c_{t+1,2}^m. \quad (1)$$

In equation (1), $c_{t,1}^a$ is an individual's consumption of the agricultural good while $c_{t,1}^m$ is his consumption of the manufactured good when he is young, and $c_{t+1,2}^a$ is his consumption of the agricultural good while $c_{t+1,2}^m$ is his consumption of the manufactured good when he is old. The price of the agricultural good is p_t^a, and the price of the manufactured good is p_t^m. A young individual faces the following budget constraint:

$$p_t^a c_{t,1}^a + p_t^m c_{t,1}^m + \frac{1}{1+r_t} p_{t+1}^a c_{t+1,2}^a + \frac{1}{1+r_t} p_{t+1}^m c_{t+1,2}^m = w_t. \quad (2)$$

Utility maximization yields

$$c_{t,1}^a = \frac{\theta}{(1+\rho)p_t^a} w_t, \quad (3a)$$

$$c_{t,1}^m = \frac{1-\theta}{(1+\rho)p_t^m} w_t, \quad (3b)$$

$$c_{t+1,2}^a = \frac{\rho\theta(1+r_t)}{(1+\rho)p_{t+1}^a} w_t, \quad (3c)$$

$$c_{t+1,2}^m = \frac{\rho(1+r_t)(1-\theta)}{(1+\rho)p_{t+1}^m} w_t. \quad (3d)$$

From a consumer's utility maximization above, the absolute values of the elasticities of demand for the agricultural good and the manufactured good are one. Also, the amount of saving of a young individual is

$$s_t = \frac{\rho}{1+\rho} w_t. \tag{4}$$

An individual allocates saving on land and capital. When the price of land is q_t, the return to land in period t is $\frac{q_{t+1}+\mu_{t+1}}{q_t}$. The return to capital is $1 + r_{t+1}$. On the one hand, if the return to land is higher than that for capital, demand for capital will be zero. On the other hand, if the return to land is lower than that for capital, demand for land will be zero. For the demand of capital and the demand for land both to be strictly positive, the return of the two assets should be equal in equilibrium:

$$\frac{q_{t+1}+\mu_{t+1}}{q_t} = 1 + r_{t+1}. \tag{5}$$

2.2. Firm behavior

Market structure for the agricultural sector is perfectly competitive. The agricultural good is produced by labor and land. The number of individuals employed in the agricultural sector is L_t^a. For the constant $z \in (0,1)$, the level of agricultural output is $(L_t^a)^z T^{1-z}$. With this constant returns to scale production function, z is the share of agricultural revenue going to labor and $1 - z$ is the share of agricultural revenue going to land.

The manufactured good is produced by labor and capital. There are m_t identical firms producing the manufactured good.[7] Like Neary (2003) and Qiu and Zhou (2007), manufacturing firms are assumed to engage in Cournot competition. Like Zhou (2004, 2007, 2013), we assume that a manufacturing firm chooses from a continuum of technologies to maximize its profit. The level of technology is indexed by a positive number n, and a higher value of n indicates a more advanced technology. For technology n, $f(n)$ is the fixed cost in terms of the units of capital used, and $\beta(n)$ is the marginal cost in terms of the units of labor used. To capture the substitution between fixed and marginal costs of production, we assume that the level of fixed costs increases while the level of marginal cost decreases with the level of technology: $f'(n) > 0$ and $\beta'(n) <$

[7] To ensure a firm makes a profit of zero, the number of manufacturing firms is a real number rather than restricted to be an integer number.

0.[8] We also assume $f''(n) \geq 0$ and $\beta''(n) \geq 0$: fixed costs increase at a nondecreasing rate and marginal cost decreases at a nonincreasing rate with the level of technology.

A representative manufacturing firm's level of output is x_t. Since there is no depreciation of capital and the price of capital does not change over time, the user cost of capital under perfect foresight is r_t. For a manufacturing firm, its revenue is $p_t^m x_t$, cost of labor is $\beta(n_t)x_t w_t$, and rental cost of capital is $f_t r_t$. Thus, its profit is

$$p_t^m x_t - \beta(n_t)x_t w_t - f_t r_t.$$

A manufacturing firm takes the wage rate and the interest rate as given and chooses output and technology to maximize its profit. The first order condition for a firm's optimal output choice is

$$p_t^m + x_t \frac{\partial p_t^m}{\partial x_t} - \beta(n_t)w_t = 0. \quad (6)$$

The first order condition for a firm's optimal technology choice is

$$-\beta'(n_t)x_t w_t - f'(n_t)r_t = 0. \quad (7)$$

From equation (7), when a firm's level of output increases, it chooses a more advanced technology.

Firms enter the manufacturing sector until the level of profits is zero.[9] Zero profit for a manufacturing firm requires that

$$p_t^m x_t - \beta(n_t)x_t w_t - f_t r_t = 0. \quad (8)$$

2.3. Market-clearing conditions

For the market for the manufactured good, the demand is the sum of the amount used for capital accumulation and the amount used for consumption. The amount of the manufactured good used for capital accumulation in a period is $K_{t+1} - K_t$, and the amount used for consumption for old and young individuals is $L\left(c_{t-1,2}^m + c_{t,1}^m\right)$. Thus, total demand for the manufactured good in period t is $K_{t+1} - K_t + L\left(c_{t-1,2}^m + c_{t,1}^m\right)$. Each of the m_t firms supplies x_t units of the manufactured good and total supply of the manufactured good in period t is $m_t x_t$. The clearance of the market for the manufactured good requires that

[8] Levinson (2006) provides an example of the choice of two technologies for loading and unloading goods in the transportation sector: one technology uses containers while the other uses longshoremen. Compared with the other technology, the technology uses containers has a much higher level of fixed costs because specially designed ports, cranes, and containers need to be built, but the marginal cost is much lower.

[9] For examples of models in which firms engage in Cournot competition and earn zero profits, see Dasgupta and Stiglitz (1980), Sections 3.7 and 4.5 of Brander (1995), and Zhang (2007).

$$K_{t+1} - K_t + L\left(c_{t-1,2}^m + c_{t,1}^m\right) = m_t x_t. \tag{9}$$

For a firm producing x_t, let Σ denote the sum of all other firms' output. From (9), we have

$$x_t + \Sigma = K_{t+1} - K_t + L\left(c_{t-1,2}^m + c_{t,1}^m\right).$$

Under Cournot competition, a firm treats other firms' outputs as given when it chooses its output. That is, for a firm choosing x_t, it treats Σ as given. With this in mind, partial differentiation of the above equation yields

$$\frac{\partial x_t}{\partial p_t^m} = \frac{\partial\left[K_{t+1} - K_t + L\left(c_{t-1,2}^m + c_{t,1}^m\right)\right]}{\partial p_t^m} = \frac{\partial(K_{t+1} - K_t)}{\partial p_t^m} + L\left(\frac{\partial c_{t-1,2}^m}{\partial p_t^m} + \frac{\partial c_{t,1}^m}{\partial p_t^m}\right)$$

$$= \frac{\partial(K_{t+1} - K_t)}{\partial p_t^m} + L\left(\frac{\partial c_{t-1,2}^m}{\partial p_t^m}\frac{p_t^m}{c_{t-1,2}^m}\frac{c_{t-1,2}^m}{p_t^m} + \frac{\partial c_{t,1}^m}{\partial p_t^m}\frac{p_t^m}{c_{t,1}^m}\frac{c_{t,1}^m}{p_t^m}\right).$$

Since the absolute value of the elasticity of a consumer's demand for the manufactured good is one ($\frac{\partial c_{t-1,2}^m}{\partial p_t^m}\frac{p_t^m}{c_{t-1,2}^m} = -1$ and $\frac{\partial c_{t,1}^m}{\partial p_t^m}\frac{p_t^m}{c_{t,1}^m} = -1$), the above equation yields

$$\frac{\partial x_t}{\partial p_t^m} = \frac{\partial(K_{t+1} - K_t)}{\partial p_t^m} - \frac{m_t x_t - (K_{t+1} - K_t)}{p_t^m}.$$

Plugging this result into equation (6) (the condition for a manufacturing firm's optimal output choice) yields

$$p_t^m\left[1 - \frac{x_t}{p_t^m}\frac{1}{\frac{\partial(K_{t+1} - K_t)}{\partial p_t^m} - \frac{m_t x_t - (K_{t+1} - K_t)}{p_t^m}}\right]\beta(n_t) w_t = 0. \tag{10}$$

For the market for the agricultural good, the demand from old individuals is $Lc_{t-1,2}^a$ and the demand from young individuals is $Lc_{t,1}^a$. Thus, total demand of the agricultural good in period t is $L\left(c_{t-1,2}^a + c_{t,1}^a\right)$. Total supply of the agricultural good in period t is $(L_t^a)^z T^{1-z}$. The clearance of the market for the agricultural good requires that $L\left(c_{t-1,2}^a + c_{t,1}^a\right) = (L_t^a)^z T^{1-z}$. Combination of this result with equation (9) yields

$$\frac{p_t^a (L_t^a)^z T^{1-z}}{p_t^m m_t x_t} = \frac{L\left(c_{t-1,2}^a + c_{t,1}^a\right)}{K_{t+1} - K_t + L\left(c_{t-1,2}^m + c_{t,1}^m\right)}. \tag{11}$$

For a worker, the return from being employed in the manufacturing sector is w_t, and the return from being employed in the agricultural sector is $zp_t^a (L_t^a)^{z-1} T^{1-z}$. Since a worker may choose to be employed in either sector, the returns in the two sectors should be equal in equilibrium:

$$w_t = zp_t^a (L_t^a)^{z-1} T^{1-z}. \tag{12}$$

For the market for labor, the demand for labor is the sum of demand from the agricultural sector and that from the manufacturing sector. The demand for labor from the agricultural sector is L_t^a. Each of the m_t firms demands $\beta(n_t)x_t$ units of labor, and demand from the manufacturing sector is $m_t\beta(n_t)x_t$. Thus, total demand for labor in period t is $L_t^a + m_t\beta(n_t)x_t$. Total supply of labor in period t is L. The clearance of the labor market requires that

$$L_t^a + m_t\beta(n_t)x_t = L. \tag{13}$$

For the market for capital, each of the m_t firms demands $f(n_t)$ units of capital, and the total demand for capital in period t is $m_t f(n_t)$. Total supply of capital in period t is K_t. The clearance of the market for capital requires that

$$m_t f(n_t) = K_t. \tag{14}$$

For the market for assets, a young individual's demand for assets is $\rho w_t/(1+\rho)$, and total demand for assets in period t is $L\rho w_t/(1+\rho)$. The supply of assets in a period is the sum of the value of capital $p_t^m K_{t+1}$ and the value of land $q_t T$. Thus, total supply of assets in period t is $p_t^m K_{t+1} + q_t T$. The clearance of the market for assets requires that

$$\frac{\rho L}{1+\rho} w_t = p_t^m K_{t+1} + q_t T. \tag{15}$$

The rent to land in period t is the value marginal product of land in the agricultural sector:

$$\mu_t = (1-z)p_t^a (L_t^a)^z T^{-z}. \tag{16}$$

For a given value of the initial capital stock K_0, the equilibrium path for this economy is solved by equations (5) and (7)-(16). Following Eaton (1987, p. 327), the manufactured good is used as the numeraire: $p_t^m \equiv 1$.[10]

3. The steady state

In this section, we study the properties of the steady state. In a steady state, variables do not change over time. We drop time subscripts for steady-state variables. From equations (5), (7)-(8), and (10)-(16), the steady state is defined by the following set of ten equations defining ten variables $r, w, m, n, p^a, L^a, x, q, u$, and K as functions of exogenous parameters:

$$\frac{1+\mu}{q} = 1 + r, \tag{5*}$$

$$-w\beta'(n)x - rf'(n) = 0, \tag{7*}$$

[10] The choice of numeraire will not affect equilibrium values of real variables. For nominal variables such as the wage rate, the equilibrium wage rate should be interpreted as the wage rate in terms of the price of the manufactured good.

$$x - w\beta(n)x - rf(n) = 0, \tag{8*}$$

$$1 - \frac{1}{m} - w\beta(n) = 0, \tag{10*}$$

$$\frac{\theta}{1-\theta} = \frac{p^a (L^a)^z T^{1-z}}{mx}, \tag{11*}$$

$$w = zp^a (L^a)^{z-1} T^{1-z}, \tag{12*}$$

$$\beta(n)mx + L^a = L, \tag{13*}$$

$$mf(n) = K, \tag{14*}$$

$$\frac{\rho L}{1+\rho} - qT = K, \tag{15*}$$

$$\mu = (1-z)p^a (L^a)^z T^{-z}. \tag{16*}$$

Equation (10*) is based on $K_{t+1} - K_t = 0$ and $\frac{\partial (K_{t+1} - K_t)}{\partial p_t^m} = 0$ in the steady state. Equation (11*) is based on the observation that with the specification of the utility function, the ratio between total spending on the agricultural good and that on manufactured good is $\theta/(1-\theta)$ when there is no capital accumulation in the steady state.

To conduct comparative statics of the steady state, we need to reduce the system of ten equations to a smaller number of equations so that it is manageable. First, from equation (12*), the number of individuals employed in the agricultural sector is

$$L^a = T\left(\frac{zp^a}{w}\right)^{\frac{1}{1-z}}. \tag{17}$$

Second, from equations (5*) and (16*), the price of land is

$$q = \frac{(1-z)wL^a}{rzT}. \tag{18}$$

Third, plugging the value of x from (8*) into equation (11*), the interest rate is

$$r = \frac{(1-\theta)(1-\beta w)^2 wL^a}{\theta f z}. \tag{19}$$

With the above manipulation, the system of ten equations reduces to the following system of three equations defining three endogenous variables w, n, and p^a as functions of exogenous parameters:[11]

$$\Omega_1 \equiv -wf\beta' - (1-\beta w)f' = 0, \tag{20a}$$

[11] The derivations of equations (20a)-(20c) are as follows. First, equation (20a) is derived by plugging the value of x from (8*) into equation (7*). Second, from equations (10*) and (14*), $K = f/(1-\beta w)$. Equation (20b) is derived by plugging this value of K and the value of q (derived from plugging equation (19) into (18)) into equation (15*). Third, plugging the value of m from (10*) and the value of x from (8*) into equation (13*) yields $\frac{\beta r f}{(1-\beta w)^2} + L^a = L$. Plugging the value of r from (19) into this equation and replacing L^a by using (12*) yields equation (20c).

$$\Omega_2 \equiv \frac{f}{1-\beta w} + \frac{\theta f(1-z)}{(1-\theta)(1-\beta w)^2} - \frac{\rho w L}{1+\rho} = 0, \tag{20b}$$

$$\Omega_3 \equiv (1-\theta)\beta w T z^{\frac{1}{1-z}} (p^a)^{\frac{1}{1-z}} + \theta T z^{\frac{1}{1-z}} (p^a)^{\frac{1}{1-z}} - \theta L w^{\frac{1}{1-z}} = 0. \tag{20c}$$

To understand equations (20a)-(20c), first, equation (20a) comes from a firm's optimal choice of technology. Second, equation (20b) is the equilibrium condition on the market for assets: $\frac{f}{1-\beta w}$ is the value of total capital stock because f is the value of capital stock of a firm and $\frac{1}{1-\beta}$ is the number of firms, $\frac{\theta f(1-z)}{(1-\theta)(1-\beta w)^2}$ is the value of land, and $\frac{\rho w L}{1+\rho}$ is the total amount of saving. Third, equation (20c) follows from labor market clearance.

Partial differentiation of equations (20a)-(20c) with respect to w, n, p^a, T, L, ρ, z, and θ yields

$$\begin{pmatrix} \frac{\partial \Omega_1}{\partial n} & \frac{\partial \Omega_1}{\partial w} & 0 \\ \frac{\partial \Omega_2}{\partial n} & \frac{\partial \Omega_2}{\partial w} & 0 \\ \frac{\partial \Omega_3}{\partial n} & \frac{\partial \Omega_3}{\partial w} & \frac{\partial \Omega_3}{\partial p^a} \end{pmatrix} \begin{pmatrix} dn \\ dw \\ dp^a \end{pmatrix} = -\begin{pmatrix} 0 \\ 0 \\ \frac{\partial \Omega_3}{\partial T} \end{pmatrix} dT - \begin{pmatrix} 0 \\ \frac{\partial \Omega_2}{\partial L} \\ \frac{\partial \Omega_3}{\partial L} \end{pmatrix} dL$$

$$-\begin{pmatrix} 0 \\ \frac{\partial \Omega_2}{\partial \rho} \\ 0 \end{pmatrix} d\rho - \begin{pmatrix} 0 \\ \frac{\partial \Omega_2}{\partial z} \\ \frac{\partial \Omega_3}{\partial z} \end{pmatrix} dz - \begin{pmatrix} 0 \\ \frac{\partial \Omega_2}{\partial \theta} \\ \frac{\partial \Omega_3}{\partial \theta} \end{pmatrix} d\theta. \tag{21}$$

For stability (see the Appendix for a more detailed discussion), we assume that the determinant of the coefficient matrix of endogenous variables of (22) is negative (Turnovsky, 1977, chap. 2):[12]

$$\Delta \equiv \frac{\partial \Omega_3}{\partial p^a}\left(\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n}\right) < 0.$$

A country's comparative advantage in producing the manufactured good is measured by the ratio of the price of the manufactured good to that of the agricultural good. Because the price of the manufactured good is normalized to one, the price of the agricultural good is also the relative price between the agricultural good and the manufactured good. Thus, the price of the agricultural good measures a country's comparative advantage in producing the manufactured good. For countries in autarky, the higher the price of the agricultural good in a country, the higher this country's comparative advantage in producing the manufactured good.

[12] As shown in the Appendix, for some specifications of the fixed and marginal costs such as $f(n) = n^2$ and $\beta(n) = 1/n$, it can be checked that this assumption is valid.

How resource abundance affects technology choice in a country is an interesting issue. In this model, other things equal, a country with a higher amount of land is viewed as more resource abundant. Suppose two countries differ only in land endowments. The following proposition studies the impact of a change in the level of resource abundance.

Proposition 1: The wage rate, the level of technology, the number of manufacturing firms, and total capital stock are not affected by the level of land endowment. Other things equal, a country with a lower amount of natural resources has a comparative advantage in producing the manufactured good.

Proof: Applying Cramer's rule to (21) yields

$$\frac{dw}{dT} = 0,$$

$$\frac{dn}{dT} = 0,$$

$$\frac{dp^a}{dT} = \frac{\partial \Omega_3}{\partial T}\left(\frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n} - \frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w}\right)/\Delta < 0.$$

From equation (10*), since n and w do not change with T, m does not change with T. Since m does not change with T, from equation (14*), K will not change with T. ■

To understand the result that the wage rate is not affected by the amount of land, from equation (12) the wage rate is determined by three factors: the number of individuals employed in the agricultural sector, the amount of land, and the price of the agricultural good. First, in this model, as argued in the next paragraph, the amount of land does not affect the equilibrium number of individuals employed in the agricultural sector. Second, from equation (12), other things equal, a higher amount of land will lead to an increase in the wage rate. Third, however, in equation (12), the price of the agricultural good is endogenously determined and it is a function of the amount of land. If the amount of land increases, the price of the agricultural good decreases. The second and the third effect have opposite implications on the wage rate, and the elasticity of demand for the agricultural good plays a key role in determining which effect is larger (Clarke and Summers, 1980). In this model, since this elasticity of demand is one, the second and third effects cancel each other out in equilibrium. Overall, the equilibrium wage rate is not affected by the amount of land.

In equation (20c), by using (17) to replace p^a with L^a, the resulting equation and equations (20a) and (20b) form a system of three equations defining three endogenous variables w, n, and

L^a as functions of exogenous parameters. From this system of three equations, applying Cramer's rule reveals that the number of individuals employed in the agricultural sector is not affected by the amount of land. From equation (19), the interest rate is determined by the wage rate, the level of technology, and the number of individuals employed in the agricultural sector. Because none of the three variables is affected by the amount of land, a change in the amount of land does not affect the equilibrium interest rate. In the literature, it has been argued that a higher amount of resources leads to a lower interest rate. Here we show there is no monotonic relationship between the interest rate and the level of resource endowment.

From the specification of the production function of the agricultural good, a lower value of z means that the share of agricultural revenue going to land increases. The following proposition studies the impact of an increase in the share of agricultural revenue going to land on technology choice and the wage rate.

Proposition 2: In the steady state, an increase in the share of agricultural revenue going to land decreases the wage rate and the equilibrium level of technology.

Proof: Applying Cramer's rule to (21) yields

$$\frac{dw}{dz} = -\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial z}\frac{\partial \Omega_3}{\partial p^a}/\Delta > 0,$$

$$\frac{dn}{dz} = \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial z}\frac{\partial \Omega_3}{\partial p^a}/\Delta > 0. \blacksquare$$

The intuition behind results in Propositions 1 and 2 that the wage rate is not affected by the amount of land but that the wage rate is affected by the share of agricultural revenue going to land is as follows. When the amount of land T increases, the price of the agricultural good decreases. As a result, the value marginal product of labor does not change, and the wage rate is not affected by the amount of land. When the share of agricultural revenue going to land z increases, might the price of the agricultural good adjust so that the wage rate will not be affected by z? No. The reason is that a change in the amount of land affects the supply of the agricultural good and thus the price of the agricultural good decreases, while a change in the share of agricultural revenue going to land may not affect the supply of the agricultural good and thus the price of the agricultural good may not adjust. When the share of agricultural revenue going to land increases, the value marginal product of labor decreases and thus the wage rate also decreases.

A more detailed illustration of Proposition 2 is as follows. Equations (20a) and (20b) form a system of two equations defining n and w as functions of exogenous parameters. First, equation (20a) shows that n and w are positively related. The explanation is as follows. When a more advanced technology is adopted, the marginal cost of a more advanced technology is that fixed costs increase, and the marginal benefit is that the marginal cost of labor decreases. A higher wage rate makes the adoption of a more advanced technology more profitable because the saving of marginal cost will be higher. Second, remember that (20b) is the condition for the equilibrium in the asset market. In equation (20b), an increase in the value of z increases the marginal product of labor. Thus, the value of land decreases and supply of asset might be smaller than the demand for asset. That is, $\frac{\partial \Omega_2}{\partial z} < 0$. To maintain the equilibrium in the asset market, the wage rate increases. That is, $\frac{\partial \Omega_2}{\partial w} > 0$.[13] The explanation of this mathematical result is as follows. For the supply of asset, an increase in the wage rate is positively related to the number of firms.[14] Other things equal, a higher number of firms means a higher value of total capital stock. Also, an increase in the wage rate is positively related to the level of output of a firm because a firm needs to produce a higher level of output to break even when the wage rate increases. When both the number of manufacturing firms and the level of output of a firm increase, the value of output in the manufacturing sector increases. With the specification of a homothetic utility function, as shown in equation (11*), the ratio between the value of output in the manufacturing sector and that in the agricultural sector is constant. Thus, if the value of output in the manufacturing sector increases, the value of output in the agricultural sector will also increase. Since the value of land is a fixed percentage of the value of output in the agricultural sector, the value of land increases with the value of output in the agricultural sector. This means that the value of land increases with the wage rate. Since both the capital stock (first term in the middle of equation (20b)) and the value of land (second term in the middle of equation 20b)) increase with the wage rate, the supply of asset

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[13] This inequality can be demonstrated as follows. From (20b), $w\frac{\partial \Omega_2}{\partial w} = \frac{f\beta w}{(1-\beta w)^2} + \frac{2(1-z)\theta f\beta w}{(1-\theta)(1-\beta w)^3} - \frac{\rho w L}{1+\rho} = \frac{f\beta w}{(1-\beta w)^2} + \frac{2(1-z)\theta f\beta w}{(1-\theta)(1-\beta w)^3} - \frac{f}{1+\rho} - \frac{(1-z)\theta f}{(1-\theta)(1-\beta w)^2} = \frac{f(2\beta w-1)}{(1-\beta w)^2} + \frac{(1-z)\theta f(3\beta w-1)}{(1-\theta)(1-\beta w)^3}$. From equation (10*), for firms to engage in oligopolistic competition, the number of firms should not be smaller than two. This leads to $\beta w \geq 1/2$. Thus, $\frac{\partial \Omega_2}{\partial w} > 0$.

[14] Since the price of the manufactured good is normalized to one, a higher wage rate means that the price of the manufactured good as a markup over marginal cost is smaller. This lower markup is possible when the number of manufacturing firms increases.

increases with the wage rate. While the demand for asset (third term in the middle of equation (20b)) increases with the wage rate in a linear way, the supply of asset increases with the wage rate in a nonlinear way and at a higher rate. Overall, an increase in the wage rate will cause an increase in the difference between supply and demand of assets. Thus, $\frac{\partial \Omega_2}{\partial w} > 0$. With $\frac{\partial \Omega_2}{\partial z} < 0$ and $\frac{\partial \Omega_2}{\partial w} > 0$, equation (20b) shows a positive relationship between the contribution of labor in the production of the agricultural good and the wage rate.

The size of the market is positively related to the size of the population. The following proposition studies the impact of an increase in population.

Proposition 3: An increase in the size of the population increases the wage rate, the level of technology, and total capital stock. Other things equal, a country with a higher population has a comparative advantage in producing the manufactured good.

Proof: Applying Cramer's rule to (21) yields

$$\frac{dw}{dL} = -\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial L}\frac{\partial \Omega_3}{\partial p^a}/\Delta > 0,$$

$$\frac{dn}{dL} = \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial L}\frac{\partial \Omega_3}{\partial p^a}/\Delta > 0,$$

$$\frac{dp^a}{dL} = \frac{\partial \Omega_2}{\partial L}\left(\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_3}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_3}{\partial n}\right)/\Delta + \frac{\partial \Omega_3}{\partial L}\left(\frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n} - \frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w}\right)/\Delta > 0.$$

Rearrangement of equation (20b) yields

$$K + \frac{(1-z)\theta mK}{1-\theta} = \frac{\rho wL}{1+\rho} = sL. \tag{22}$$

In equation (22), since w increases with L, $K + \frac{(1-z)\theta mK}{1-\theta}$ increases with L. If m increases and K does not change, from (14*), n will decrease. This will lead to a contradiction to the result that n will increase. Thus, K increases with L. ■

The intuition behind Proposition 3 is as follows. If the size of the population increases, with increasing returns in the manufacturing sector, the wage rate increases.[15] Since the level of income is higher, the amount of saving increases. The total amount of saving determines the level of capital stock. From equation (22), a higher amount of saving leads to a higher capital stock.

[15] More accurately, the ratio between the wage rate and the price of the manufactured good increases. Since the price of the manufactured good is normalized to one, this increase is reflected as an increase in the wage rate.

Since the capital stock is higher, more advanced technologies are chosen. With more advanced manufacturing technologies, a country with a higher population has a comparative advantage in producing the manufactured good.

From Propositions 1 and 3, since the United States had a higher resource endowment and a lower population than Britain in the antebellum period, United States did not have comparative advantage in producing manufactured goods at that time. This result is consistent with opinions of some politicians at that time. Alexander Hamilton, the pioneer of the infant industry argument and the first Treasure Secretary of the United States, believed that the United States did not have a comparative advantage in producing manufactured goods. It is not strange that the United States used tariffs to support the manufacturing sector at that time (Chang, 2003).

The following proposition studies the impact of an increase in the percentage of income spent on the manufactured good.

Proposition 4: In the steady state, an increase in the percentage of income spent on the manufactured good increases the wage rate and more advanced technologies are adopted.

Proof: Applying Cramer's rule to (21) yields

$$\frac{dw}{d\theta} = -\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial \theta}\frac{\partial \Omega_3}{\partial p^a}/\Delta < 0,$$

$$\frac{dn}{d\theta} = \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial \theta}\frac{\partial \Omega_3}{\partial p^a}/\Delta < 0. \blacksquare$$

The intuition behind Proposition 4 is as follows. An increase in the percentage of income spent on the manufactured good increases the demand for the manufactured good. This makes the adoption of more advanced technologies more profitable because the higher level of fixed costs can be spread over a higher level of output.

The following proposition studies the impact of an increase in the degree of patience of an individual.

Proposition 5: An increase in the degree of patience of an individual increases the wage rate, the equilibrium level of technology, and total capital stock. Other things equal, a country with more patient individuals has a comparative advantage in producing the manufactured good.

Proof: Applying Cramer's rule to (21) yields

$$\frac{dw}{d\rho} = -\frac{\partial\Omega_1}{\partial n}\frac{\partial\Omega_2}{\partial\rho}\frac{\partial\Omega_3}{\partial p^a}/\Delta > 0,$$

$$\frac{dn}{d\rho} = \frac{\partial\Omega_1}{\partial w}\frac{\partial\Omega_2}{\partial\rho}\frac{\partial\Omega_3}{\partial p^a}/\Delta > 0,$$

$$\frac{dp^a}{d\rho} = \frac{\partial\Omega_2}{\partial\rho}\left(\frac{\partial\Omega_1}{\partial n}\frac{\partial\Omega_3}{\partial w} - \frac{\partial\Omega_1}{\partial w}\frac{\partial\Omega_3}{\partial n}\right)/\Delta > 0.$$

In equation (22), since w increases with ρ and ρ itself also increases, $K + \frac{(1-z)\theta mK}{1-\theta}$ increases with ρ. If m increases and K does not change, from (14*), n will decrease. This will lead to a contradiction to the result that n increases with ρ. Thus, K increases with ρ. ■

Proposition 5 shows that an increase in the degree of patience of an individual is beneficial because more patience increases the saving rate. The reason behind this result is as follows. The amount of saving is the product of the wage rate and the saving rate. Since both the wage rate and the saving rate increase, the amount of saving increases. Because part of the additional saving is channeled into capital formation, the amount of capital stock increases. A higher level of capital stock induces firms in the manufacturing sector to choose more advanced technologies. With more advanced manufacturing technologies, a country's comparative advantage in producing the manufactured good increases.

4. Conclusion

In this paper, we have studied how resource abundance and market size affect the choice of increasing returns technologies in an overlapping-generations model in which manufacturing firms engage in oligopolistic competition. For the steady state, we have derived the following results analytically. First, we show that natural resources affect the wage rate and technology choice, but in a way different from conventional wisdom: it is the share of agricultural revenue going to land rather than the amount of land affecting the wage rate and the equilibrium level of technology. A higher share of agricultural revenue going to land decreases the wage rate. Second, an increase in the size of the population increases the wage rate, the equilibrium level of technology, and total capital stock. Since the opening to international trade can increase the size of the market like that of a population increase, this model shows that the opening to international trade could also increase a country's welfare.

There are some interesting generalizations and extensions of the model. First, we have used a special utility function with a unitary elasticity of demand. Some results such as the claim in Proposition 1 that the wage rate and the equilibrium level of technology are not affected by land endowment rely on this assumption. Extending the model to a more general utility function will be an interesting avenue for future research. Second, in this paper, we have abstracted away from political economy considerations in technology adoption. In reality, institutions and cultural factors could affect firms' technology choices. Incorporating political economy considerations into the choice of technology is an interesting avenue for future research. Third, it is valuable to extend the model to study the impact of international trade explicitly even though analytical results might not be possible. Suppose markets in different countries are integrated. If there is no transportation cost and countries have access to the same set of technologies, the wage rate and a firm's technology choice will be affected by population size and land endowment at the world level. In reality, there are transportation costs and markets are not integrated, so population size and land endowment of a country will still affect technology choice and the wage rate in a country. However, compared to the case of a closed economy, the impact of domestic population size and land endowment on technology choices could be weaker.

Appendix: Stability of the steady state

For the steady state, equations (20a) and (20b) form a system of two equations defining two endogenous variables n and w. Following the approach used in Samuelson (1983, Chap. 9), suppose that the level of technology will rise if the marginal benefit from choosing a more advanced technology is higher than the marginal cost. From equation (20a), the difference between the marginal benefit and the marginal cost of technology choice is positively related to $-wf\beta' - (1-\beta w)f'$. We also assume that equation (20b) always holds. Thus, we have

$$\dot{n} = -wf\beta' - (1-\beta w)f', \tag{A1}$$

$$\frac{f}{1-\beta w} + \frac{\theta f(1-z)}{(1-\theta)(1-\beta w)^2} - \frac{\rho w L}{1+\rho} = 0. \tag{A2}$$

Let λ denote a characteristic root for the system (A1)-(A2). That is, the value of λ is defined by

$$\begin{vmatrix} \frac{\partial \Omega_1}{\partial n} - \lambda & \frac{\partial \Omega_1}{\partial w} \\ \frac{\partial \Omega_2}{\partial n} & \frac{\partial \Omega_2}{\partial w} \end{vmatrix} = 0.$$

This leads to

$$\begin{vmatrix} \frac{\partial \Omega_1}{\partial n} & \frac{\partial \Omega_1}{\partial w} \\ \frac{\partial \Omega_2}{\partial n} & \frac{\partial \Omega_2}{\partial w} \end{vmatrix} - \lambda \frac{\partial \Omega_2}{\partial w} = 0. \tag{A3}$$

For the system (A1)-(A2) to be stable, it is necessary that $\lambda < 0$. From (A3), since $\frac{\partial \Omega_2}{\partial w} > 0$, stability of the system (A1)-(A2) requires that

$$\begin{vmatrix} \frac{\partial \Omega_1}{\partial n} & \frac{\partial \Omega_1}{\partial w} \\ \frac{\partial \Omega_2}{\partial n} & \frac{\partial \Omega_2}{\partial w} \end{vmatrix} < 0. \tag{A4}$$

From (A4), if the system formed by (20a) and (20b) linearized around the steady state is stable, it is a saddle (Perko, 2001, p. 25). Partial differentiation of (20a) and (20b) reveals that the sign of $\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n}$ is undetermined. However, for some specifications of the fixed and marginal costs such as $f(n) = n^2$ and $\beta(n) = 1/n$, it can be checked that this assumption is valid. With $f(n) = n^2$ and $\beta(n) = 1/n$, from equation (20a), it can be shown that $w = \frac{2}{3}n$. In this case, $\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n} = -18n - \frac{27n\theta(1-z)}{1-\theta} < 0$, where n is defined by (20b). Solving (20b) yields $n = \frac{2\rho L(1-\theta)}{3(1+\rho)[3(1-\theta)+9\theta(1-z)]}$.

Partial differentiation of equation (20c) reveals that $\frac{\partial \Omega_3}{\partial p^a} > 0$. With $\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n} < 0$, it is clear that stability of the steady state requires

$$\Delta \equiv \frac{\partial \Omega_3}{\partial p^a}\left(\frac{\partial \Omega_1}{\partial n}\frac{\partial \Omega_2}{\partial w} - \frac{\partial \Omega_1}{\partial w}\frac{\partial \Omega_2}{\partial n}\right) < 0.$$

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